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1.0 INTRODUCTION

The 3D-Cockpit Display of Traffic Information (3D-CDTI) is a flight deck tool that presents aircrew with:

- proximal traffic aircraft location, their current status and flight plan data
- strategic conflict detection and alerting
- automated conflict resolution strategies
- the facility to graphically plan manual route changes
- time-based, in-trail spacing on approach

The CDTI is manipulated via a touchpad on the flight deck, and by mouse when presented as part of a desktop flight simulator.

1.1 DOCUMENT PURPOSE

This manual is maintained to provide basic information on the CDTI for:

- pilots participating in research activities
- research partners in government and industry

1.2 DOCUMENT UPDATES

Document updates are available by visiting the Flight Deck Research Group at:

- <http://human-factors.arc.nasa.gov/ihh/cdti/download.html>

1.3 CONTACT INFORMATION

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2.0 DISPLAY BASICS

This section describes the CDTI's standard navigation elements and display controls.

2.1 STANDARD NAVIGATION ELEMENTS

The CDTI's standard navigation elements are referenced below, and described on the following pages.

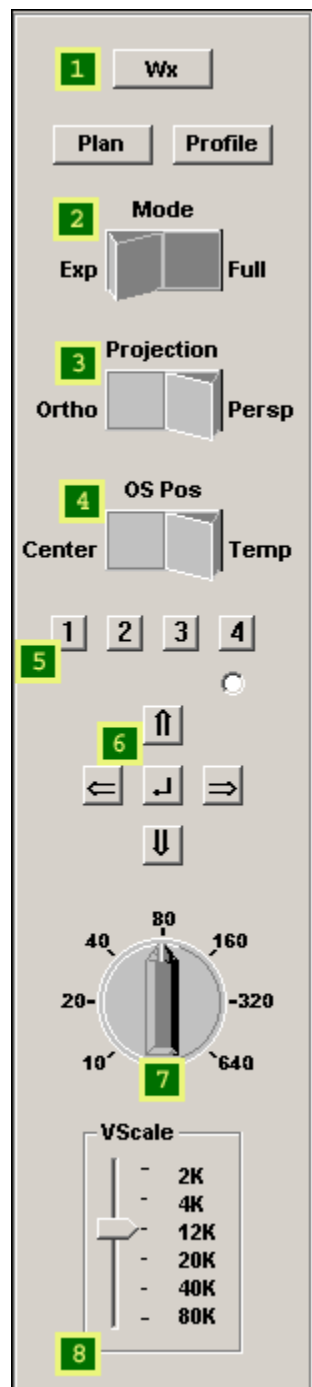


Display 01 Basic elements within the CDTI

- 01** Ground Speed (GS)
Indicated Air Speed (IAS)
Altitude (ALT)
Wind direction / Wind speed in knots
- 02** Current heading
- 03** Current display range (NM)
- 04** Next VOR / waypoint
Time to arrive at next VOR / waypoint (Zulu)
Distance to next VOR / waypoint
- 05** Heading bug
- 06** Flight Plan
- 07** Display range mid-point
- 08** Heading line
- 09** Ownship

2.2 DISPLAY PANEL

The panel that appears with the CDTI controls a variety of display options, detailed below. Other display options are located on the tool bar below the CDTI.



01 Weather Projection (Wx)

Plan view (Plan)

Profile view (Profile)

Operation – press to turn ON

02 Mode – Expanded view: top down, limited 2D view

Mode – Full view: top down, complete view (permits 3D)

Operation – press to toggle between modes

03 Projection – Orthographic view

Projection – Perspective view

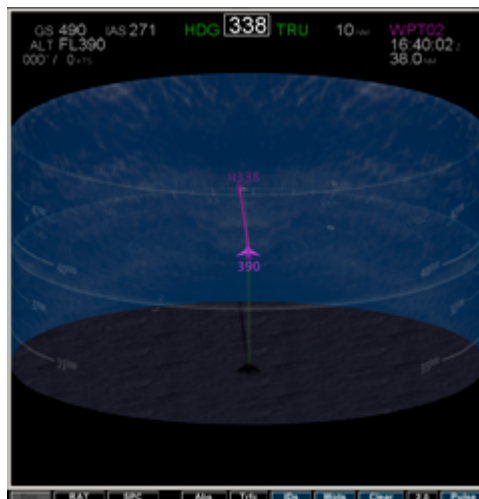
Operation – press to toggle between projection type

04 Ownship position – Center location: Ownship depicted at center

Ownship position – Temporal location: Ownship depicted at the bottom of the display and traffic depicted can reach Ownship within 10min.

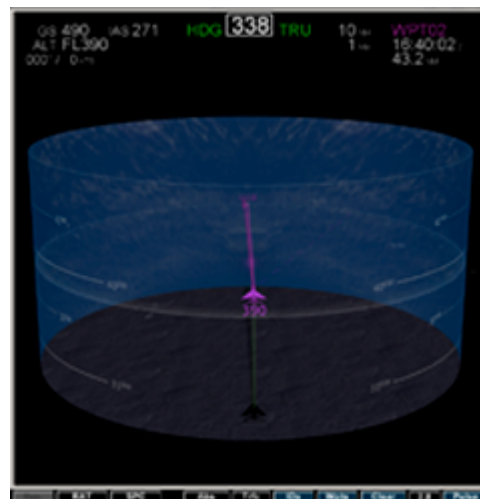
Operation – press to toggle between Ownship position

Sample views in Full mode



Projection = Ortho

OS Pos = Center



Projection = Persp

OS Pos = Temp

Display 02 This panel controls how the CDTI looks

05 Display memory settings (1 through 4) – no label
Operation – Click radio button, then number, to set view

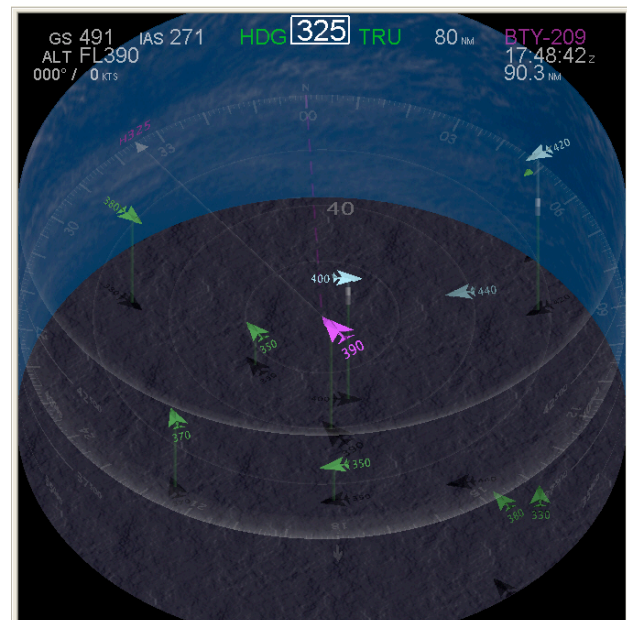
06 Ownship direction on display (4-way arrows) – no label
Return to last view ("undo" key button) – no label
Operation – press a button to reorient ownship

07 Range displayed – no label. The range varies from 10NM to 640NM.
Operation – press number to set range

08 Vertical scale displayed (VScale) – scale represents thousand feet above and below Ownship. The range varies from 2,000ft to 80,000ft.
Operation – move slider to set range

2.3 3D-DISPLAY ACTIVATION

To 'rotate' the display into a 3D orientation, first set the Mode to Full (in the control panel). Within the CDTI display area, right-click and hold while moving the mouse to modify the display's orientation, release the mouse button to set.



Display 03 3D CDTI view.

2.4 TOOL BAR

The panel that appears below the CDTI controls various display options and access to tools, detailed below. Other display options are located on the "panel" that accompanies the CDTI.



Display 04 This panel controls several display options and provides access to CDTI tools.

1

Automated resolutions (Res.)

Operation – press to access options

2

Alert button

Operation – press to view new conflicts

3

Route Analysis Tool (RAT)

Operation – press to turn ON / OFF

4

Spacing (SPC)

Operation – press to access / disengage

5

Absolute / Relative altitude tail tags (Abs / Rel)

Operation – press to toggle between Abs / Rel

6

Traffic button

Operation – press to dim aircraft and waypoints on the display

7

Flight IDs (IDs)

Operation – press to toggle between all ON / OFF

8

Waypoints (Wpts)

Operation – press to toggle between all ON / OFF

9

Clear (Clear)

Operation – press to declutter display



Temporal length of pulse predictors (0.0)

Operation – Left click to decrease / right click to increase

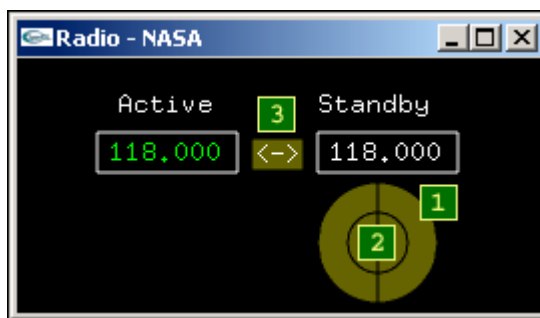


Pulse (Pulse)

Operation – press to toggle between ON / OFF

2.5 RADIO PANEL

The radio panel is used for communication with ATC



Display 05 This display allows pilots to dial into different radio frequencies.

01 Outer radio dial – In standby, right side decreases / left side increases frequency value *before* the decimal point.

Operation – click to increase/decrease

02 Inner radio dial – In standby, right side decreases / left side increases frequency value *after* the decimal point.

Operation – click to increase/decrease

03 Active/Standby toggle

Operation – click to move frequency value to active mode.

3.0 AIRCRAFT SYMBOLOGY AND INTENT

This section describes the CDTI's aircraft symbology and intent communication.

3.1 OWNERSHIP

Ownship position on the CDTI is indicated by a magenta chevron. Exact aircraft location lies at the tip of the chevron. If ownship come into conflict with another aircraft, the chevron turns yellow.



Symbology 01 Ownship symbol colors.

3.2 TRAFFIC

Traffic aircraft are represented by chevrons on the display. Exact aircraft location lies at the tip of each chevron. AFR aircraft are depicted with a 2-minute intent path off the nose of the aircraft, whereas IFR aircraft are not depicted with an intent path.

3.2.1 ALTITUDE [COLOR CODING]

Traffic aircraft are displayed in one of three primary altitude-based colors.

Traffic 700 feet or more below ownship altitude are green.

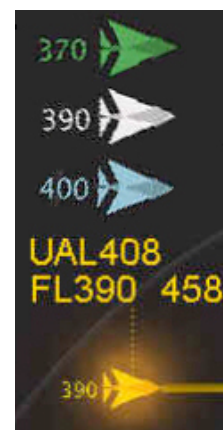
Traffic less than 700 feet above or below ownship altitude are white.

Traffic 700 feet or more above ownship altitude are blue.

Traffic in conflict with ownship are yellow.

3.2.2 ALTITUDE [BRIGHTNESS CODING]

A temporal filter exists such that traffic aircraft within 10 minutes of reaching ownship are "brighter" than other traffic aircraft on the display.



Symbology 02
Color-coding for traffic aircraft.

3.2.3 ALTITUDE: RELATIVE VS. ABSOLUTE (Item 4 on the CDTI toolbar)

Traffic within the vertical altitude band subject to surveillance each have an altitude tag (or tail tag). Absolute (Abs) altitude is represented by a two to three digit number (x 100 feet). An absolute altitude might read "350" indicating an altitude of 35,000 feet. When traffic altitude Relative (Rel) to ownship is indicated, a one or two digit number (x 100 feet) is presented, preceded by a + or – indicating whether the aircraft is above or below ownship's current altitude. A relative altitude might read "+10" indicating the aircraft is 1,000 feet above ownship's altitude.

Click the Abs/Rel button on the tool bar to toggle between these two settings.

*Aircraft within the lateral surveillance range of ownship, but outside the probed altitude band are shown on the display. Altitude (tail) tags are **not** appended to these aircraft.*

3.2.4 ALTITUDE [CLIMB VS. DESCENT]



Symbology 03

Aircraft in a climb.

Traffic aircraft in a climb or descent of 200 ft/min or greater are indicated by the presence of an up or down arrow adjacent to the altitude tail tag.

The flight plan associated with the climbing or descending aircraft is visually depicted with a dashed line. The color of a climb leg is depicted as blue, whereas the color of a descent leg is depicted as green.

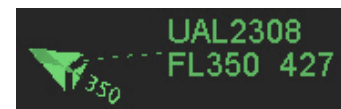


Symbology 04

Aircraft on descent

3.2.5 DATA TAGS

Data tags can be displayed for traffic. Each tag contains the aircraft Flight ID (FID), current Flight Level (FL) in feet (x 100), and Ground Speed in knots.



Symbology 05 Traffic data tag.

To turn a single aircraft data tag on, use the mouse to place the cursor over the apex of the traffic symbol and left click the mouse button. Repeat this action to turn the data tag off.

To move the data tag, use the mouse to left-click-and-hold within the border of the tag and drag to the desired location. Release the mouse to 'drop' the data tag at its new location.

To turn on **all** data tags, click the IDs button on the tool bar (item 5 on the toolbar) to toggle data tags ON and OFF.

3.3 INTENT DEPICTION

Traffic intent is depicted to the CDTI operator via aircraft predictors and flight plans, described below. Other elements such as chevron heading and altitude tail tags provide secondary information as to intent.

3.3.1 PREDICTORS

For traffic aircraft broadcasting a flight plan, predictors indicate future position over time, along the planned path of travel. Click the Pulse button on the tool bar (item 9 on the toolbar) to toggle between predictors ON and OFF.

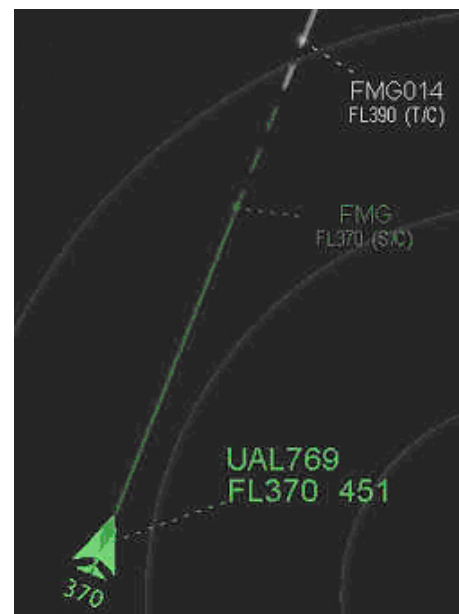
The pulse traveling the length of the predictor line correlates to the speed of the aircraft. All other elements (for example, winds) being equal, the pulse of an aircraft at 180 knots would be half as fast as an aircraft traveling at 360 knots.

To alter the temporal value of the pulse predictors (item 8 in the toolbar), move the cursor over the time and left click to reduce the value. Right click to increase the value.

3.3.2 FLIGHT PLANS

Flight plans can be viewed for traffic within the broadcast range and altitude surveillance band of the CDTI. Using a touchpad or mouse, place the cursor over the apex of the traffic symbol and dwell, highlighting the chevron. Right mouse click to display the route. Repeat this action to turn the route off.

The flight plan will include waypoints and altitude changes. Altitude change segments are indicated by a dotted line at the descent/ascent path.



Note: Intent information is color coded relative to the position and altitude of ownship. As described earlier, flight plans above ownship are blue, flight plans below ownship are green, and those at ownship's altitude white.

Symbology 04 Traffic flight plan

4.0 CONFLICT DETECTION, ALERTING AND RESOLUTION

The CDTI provides strategic conflict detection. *It is **not** designed for tactical conflict detection or resolution.*

4.1 CONFLICT DETECTION

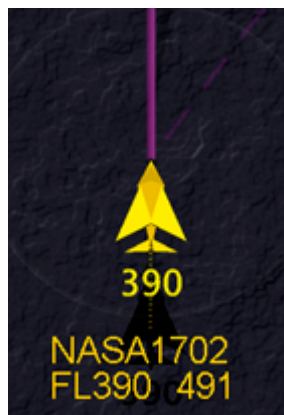
Embedded within the CDTI is logic that detects conflicts, assigns an alert level, and communicates this to the flight crew. The logic takes advantage of intent information in the form of flight plans, when available. In the absence of flight plan data the conflict detection logic operates based on aircraft state information – current heading, altitude and speed.

4.2 CONFLICT ALERTING

When a conflict is detected, the ownship symbol turns yellow. The aircraft in conflict with ownship also turns yellow, and its data block appears. The traffic aircraft data block cannot be disabled (turned off) until the conflict is resolved.

4.2.1 ALERTING LEVELS

A **LEVEL 1** conflict alert occurs according to the following characteristics:

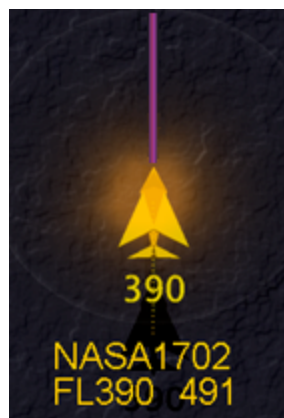


Alert 01 L1 alert

1A. Conflict Probability: Moderate	Temporal Proximity: Far Term
1B. Conflict Probability: Low	Temporal Proximity: Near Term

A Level 1 conflict results in the Ownship and traffic symbols turning yellow. The flight plan will remain the color of intent

A **LEVEL 2** conflict alert occurs according to the following characteristics:

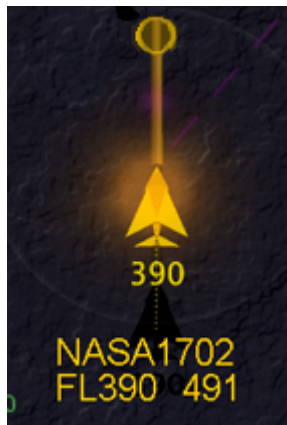


Alert 02 L2 alert

2A. Conflict Probability: Moderate	Temporal Proximity: Middle Term
2B. Conflict Probability: High	Temporal Proximity: Far Term

A level 2 conflict results in the ownship and traffic chevrons turning yellow, with a "halo" appearing around the traffic chevron. The flight plan will remain the color of intent.

A **LEVEL 3** conflict alert is best characterized as being:



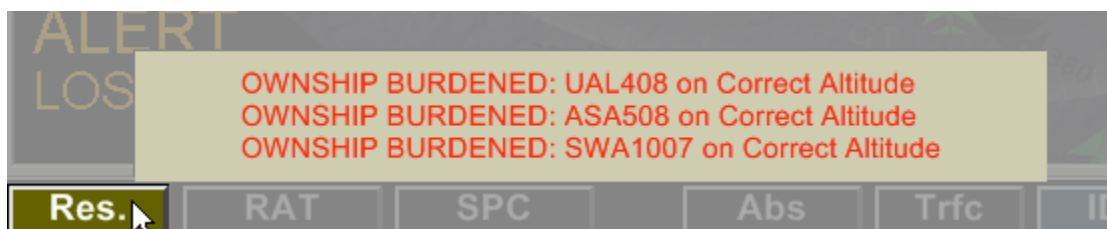
3A. Conflict Probability: High	Temporal Proximity: Near Term
3B. Conflict Probability: High	Temporal Proximity: Middle Term

A level 3 conflict results in the ownship and traffic chevrons turning yellow, with a "halo" appearing around the traffic chevron. Yellow predictor lines and over-lapping LOS 'rings' appear during a level 3 conflict.

Alert 03 L3 alert

4.3 AUTOMATED CONFLICT RESOLUTION

In the event of a traffic conflict, the resolution (RES) button in the tool bar (item 1) becomes active, as indicated by a yellow or blue button instead of gray. A yellow RES button indicates ownship is the 'burdened' aircraft – that is, ownship is required to resolve the conflict. A blue RES button indicates that ownship *is not* the burdened aircraft and is not required to resolve the conflict. To view the reasons as to why Ownship is or is not burdened, simply use the mouse to *hover* over the RES button.



CD&R 01 Resolution reasons

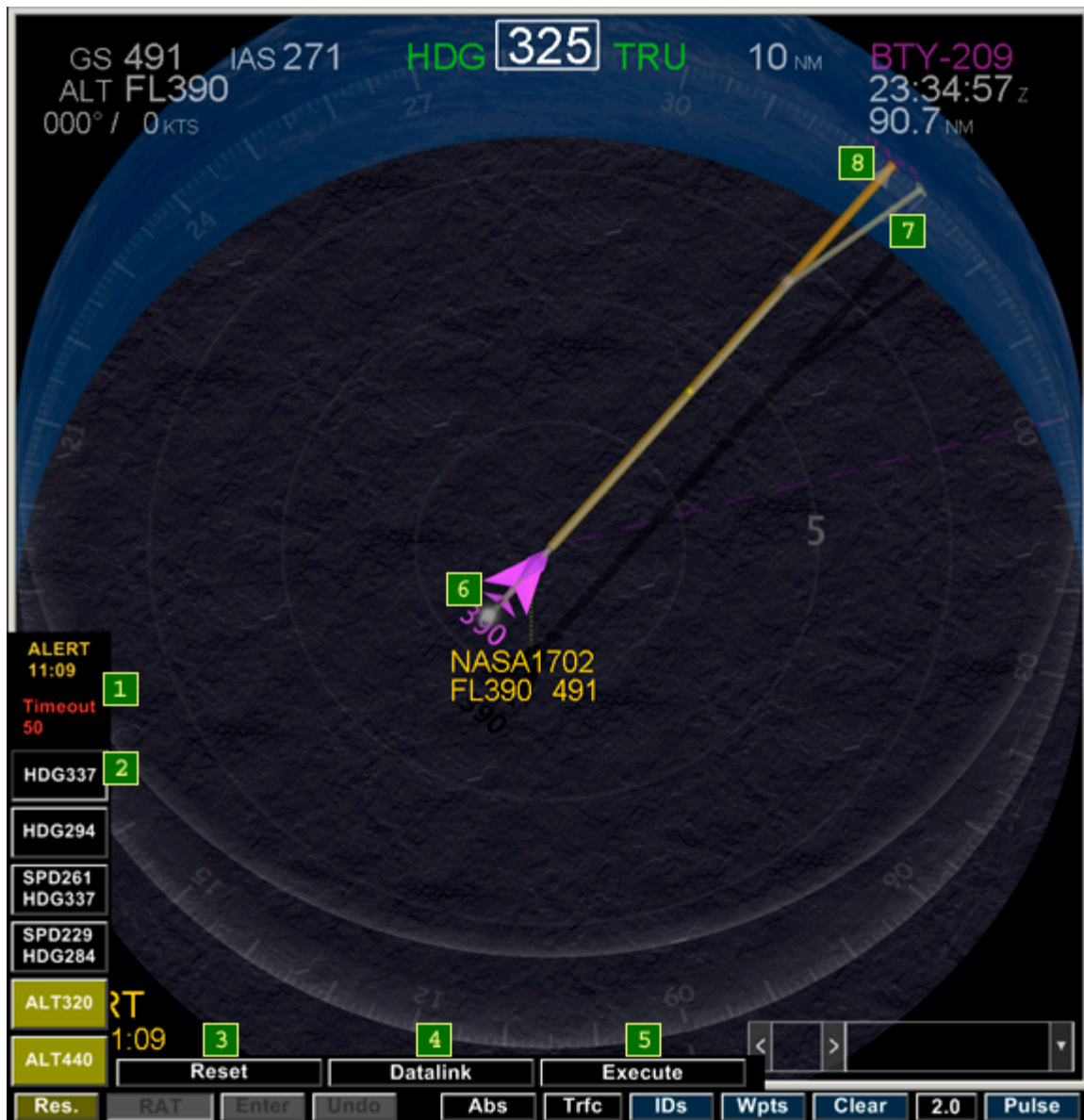
4.31 ACTIVATION OF CONFLICT RESOLUTIONS

Clicking on the RES button will produce a list of resolution alternatives, which appear directly above the button. The details of each resolution, in terms of heading, speed, or altitude change are indicated. Clicking on a resolution alternative will display the newly proposed route on the CDTI. The list of resolution strategies remain valid and executable for the time (in seconds) presented under the "timeout" message. The time to loss of separation appears at the top.

The first (uppermost) resolution strategy in the list is the most efficient in terms of minimizing any course change or fuel usage. The resolution strategies coded in black are

RTA compliant and those coded in yellow are not RTA compliant. "Executing" a resolution strategy will update ownship's flight plan.

The interface elements of an automated conflict resolution are detailed on the following page.



CD&R 02 Automatic conflict resolutions

- 01** Time to loss of separation (ALERT 00:00)& time current resolutions will remain active
- 02** List of resolution strategies

- 03** Reset – creates a new list of resolutions
Operation – press to search for different resolutions
- 04** Datalink – Transmits the route to ATC for approval
Operation – press to transmit
- 05** Execute – Executes the route on the CDTI
Operation – press to transmit
- 06** Null Point – Point at which flight plan change is calculated from. (Broadcast aircraft path cannot deviate before this point).
- 07** Proposed Route – Flight path projected based on a resolution selection.
- 08** Current Route – Flight path currently broadcast *before* the proposed route is executed. This is also the route which will remain active if a resolution is not selected.

5.0 ROUTE ANALYSIS TOOL (RAT)

The Route Analysis Tool facilitates 1) in-flight, flight crew modification of flight plans, 2) submission of proposed flight plan changes to Air Traffic Control (ATC), 3) receipt of flight plan modifications from ATC, and 4) execution of flight plan changes in the following circumstances:

- without “approval” when in free flight,
- when first approved by ATC in limited free flight operations, or
- upon receipt (uplink) from ATC, with the concurrence of the flight deck.

Appropriate uses for the RAT include the planning and implementation of flight plan changes to 1) resolve strategic conflicts with other aircraft, 2) set RTA’s at meter fixes 3) avoid weather, 4) take advantage of winds, 5) make use of more direct routing options when available, and 6) to avoid dynamic Special Use Airspace (SUA).

5.1 RAT WAYPOINT TABLE

Upon activation of the RAT, a table appears on the lower right side of the CDTI. The interface elements are detailed below.

<	1	>	2	BAMBE	3 ▾
RTA	4	▽	:		▲
ETA	5		0:30:12		
Alt	6	▽	110		▲

RAT 01 Waypoint table

- 01** Left / Right arrows – Waypoint access
Operation – Press to cycle through waypoint ID's
- 02** List of waypoint names
- 03** Up / Down arrow – Expand and collapse table
Operation – Press to activate
- 04** Required Time of Arrival (RTA) – RTA at a VOR / waypoint
Operation – Click on numbers to cycle through hours:minutes:seconds. Use up and down arrows to change the temporal value.
- 05** Estimated Time of Arrival (ETA) – ETA at the VOR / waypoint Distance (Dist); this is the estimated time of arrival to the selected waypoint based on current winds, speed etc.
- 06** Altitude (Alt) – Allows an altitude change at a designated waypoint
Operation – Use up and down arrows to change

5.2 LATERAL ROUTE MODIFICATIONS

The lateral path of ownship can be modified in three ways. An existing waypoint in the flight plan can be moved, a new waypoint created (and moved), or a waypoint deleted from the flight plan.

5.2.1 MOVING A WAYPOINT

Waypoints along a route can be selected and moved, creating a new path.

Step 1 – Turn the RAT on and move the cursor over an existing waypoint (red point on the flight path. The point will turn green when the mouse is hovered over it).

Step 2 – Click and hold on the highlighted waypoint. Drag the waypoint to a new location and 'drop' it.

Step 3 – Press Enter, then Execute on the tool bar.



RAT 02 Moving a waypoint. Route is ready to "Execute."

Note: When a proposed route is datalinked to ATC for review, it remains on the CDTI, in gray, until a reply has been received from the ground or the route passes the execution threshold – the small dot on the lubber line forward of ownship.

5.2.2 CREATING A WAYPOINT

Step 1 – Turn the RAT on, dwell over the route, and click when the arrow is over the desired location. A waypoint will be inserted.

Step 2 – Review the location of the waypoint. It can be dragged along the route path, or off to either side of the existing route.

Step 3 – Press Enter, then Execute when all route modifications are complete.



5.2.3 DELETING A WAYPOINT

RAT 03 Creating a waypoint.

Step 1 – Turn the RAT on and dwell over the waypoint on the route.

Step 2 – With the waypoint highlighted, right click once.

Step 3 – Press Enter, then Execute when all route modifications are complete.

5.3 VERTICAL ROUTE MODIFICATIONS

Step 1 – Create a waypoint along the route (see above), or select an existing waypoint.

Step 2 – Use the up and down arrows next to "Alt" in the waypoint table, to enter the desired altitude. A (climb or descent transition) waypoint is automatically created.

Step 3 – Review the altitude change segment on the CDTI. Press Enter, then Execute when all route modifications are complete.

Note: The altitude change segment can be moved along the ownship route. Left click and hold, drop to re-locate.

6.0 PDA SPACING

Paired Dependent Approach (PDA) Spacing is the initiation and execution of in-trail following during approach to landing. The goal of PDA spacing is to safely maximize the number of aircraft that can land within a given time. To achieve this, inter-aircraft spacing is optimized, such that aircraft cross the runway threshold with minimal 'lost' time between arrivals.

6.1 SPACING INITIATION

Initiating spacing requires ATC first issue ownship a "lead" aircraft to follow, along with a time-in-trail. Flight crew begins PDA Spacing by:

- Clicking the "SPC" button on the tool bar
- Selecting (clicking on) the lead aircraft on the CDTI display
- Modifying the spacing interval (time value) assigned by ATC
 - Left mouse click to decrease
 - Right mouse click to increase
- Clicking "Start" on the tool bar

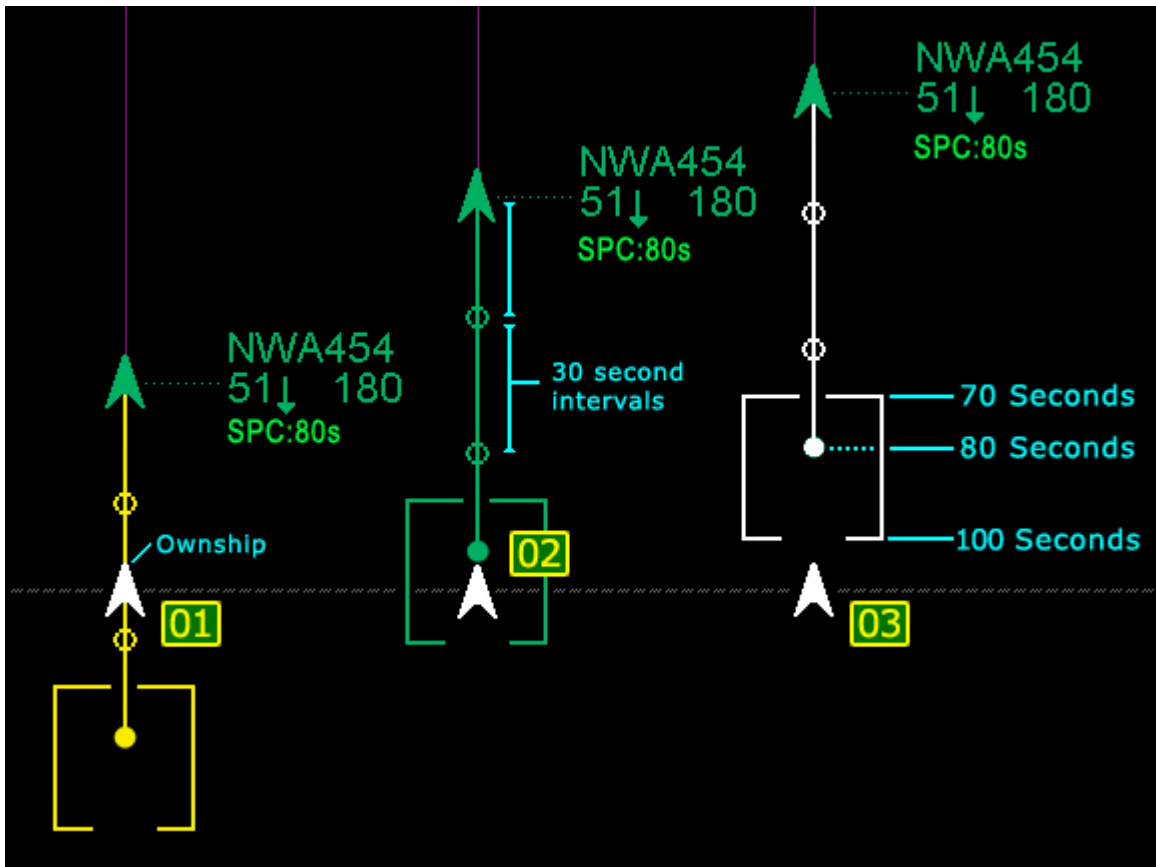


PDA 01 PDA Spacing is ready to be "Start"(ed).

The CDTI then calculates the required ownship speed for maintenance of the correct time interval ("PDA Processing" appears on the CDTI top left during data collection), and manipulates the auto-throttles appropriately ("CMD A/T" appears top left of CDTI). If a 'gap' exists the CDTI will increase ownship speed. If ownship is too close, the CDTI will slow ownship.

6.2 SPACING MONITORING

As there are instances when it is appropriate and/or necessary that flight crew intervene in a PDA operation, feedback on the CDTI is designed to facilitate this, and is described below.



PDA 02 PDA Spacing box colors are dependent on ownship position relative to the required temporal spacing value (80 seconds in the illustrated example).

- 01** If ownship is > 10 seconds ahead of the required temporal spacing value, the spacing box turns yellow.
- 02** When ownship is ≤ 10 seconds ahead of the required temporal spacing value, or ≤ 20 seconds behind the required temporal spacing value, the spacing box turns green.
- 03** If ownship is > 20 seconds behind the required temporal spacing value, the spacing box turns white.

7.0 RULES OF THE ROAD

The rules of the road are encompassed by 1) the roles and responsibilities of the pilots and 2) the set of rules utilized by the software to determine the burdened aircraft when two aircraft are predicted to lose separation. The rules are provided for informational purposes only; the software will determine the burdened aircraft and depict it according to the method outlined in section 4.3.

7.1 ROLES & RESPONSIBILITIES

AFR aircraft *must* adhere to the following rules at all times.

- Maintain a minimum separation of 5NM & 1000ft vertical separation from all aircraft.
- Resolve all conflicts where ownship is burdened at least 2 minutes before the LOS.
- Refrain from creating flight plan changes that cause LOS within 4 minutes.
- ATC may verbally assume responsibility for separating an IFR AC from an AFR AC.
- If ATC creates a predicted LOS that is within 4 minutes, ATC shall verbally assume responsibility for separating the IFR aircraft from the AFR aircraft.

AFR aircraft are *recommended* to adhere to the following rules when possible.

- AC should stay on their broadcast intent (flight plan).
- ATC should implement flight plan changes for IFR AC that do not conflict with the broadcast intent of an AFR AC well beyond 4 minutes.
- AFR aircraft should implement flight plan changes that do not conflict with the broadcast intent of any other AC well beyond 4 minutes.
- Burdened AFR AC should resolve predicted Level 2 conflicts within 2 minutes after detection (e.g., if conflict shows LOS in 8 minutes, AFR AC should resolve prior to 6 minutes to LOS).

7.2 FLIGHT RULES

IFR aircraft vs. AFR aircraft

IFR aircraft have the right of way when in conflict with AFR aircraft, except when ATC has assumed verbal responsibility.

AFR vs AFR

1) AMES aircraft *always* have the right of way when in conflict with LANGLEY aircraft (LANGLEY aircraft are always burdened).

2) Aircraft on a flight plan *always* have the right of way when in conflict with a vectored aircraft.

3) Altitude Rule: AC have the right of way when:

A - Traveling EAST (based on the magnetic compass of 0 - 179 degrees) and flying at an ODD altitude level.

B - Traveling WEST (based on the magnetic compass of 180 - 359 degrees) and flying at an EVEN altitude level.

* An AFR aircraft is burdened if not flying correct direction for altitude.

4) Level Flight Rule: AC in level flight has the right of way over a climbing or descending AC (regardless of heading).

5) Descend/Climb Rule: Descending AC have the right of way over climbing AC.

6) Left/Right Rule (when conflict angle is > 20 degrees): AC on the right at the point of conflict has the right of way during an encounter between two AC when both are level, on ascent, or descent.

7) Overtake Rule: When the angle of separation between two conflicting AC is less than 20 degrees (in other words, they are on the "same" path), the lead AC has the right of way.

Note: When none of the rules above apply to the conflict, *Ownship* assumes responsibility for resolving the conflict.

8.0 DAG-TM

Distributed Air/Ground – Traffic Management (DAG-TM) is a NAS concept in which flight crews, ATC, and AOCs employ distributed decision-making to safely facilitate user preferences and increase system capacity. The goal of DAG-TM is to enhance user flexibility/efficiency and increase system capacity, without adversely affecting system safety or restricting user accessibility to the NAS.

Known DAG-related issues relevant to CDTI use are outlined below.

RTA COMPLIANCE - I

ATC will datalink an RTA at BAMBE before Ownship's Top of Descent. Before the pilots datalink "acceptance" of the RTA, they should enter the RTA in the Waypoint Table to verify Ownship compliance. If Ownship cannot meet the RTA at BAMBE based on current aircraft specs, the ETA will become highlighted in red.

<	330	>	300	BAMBE	▼
RTA	▼	19:15:03	▲		
ETA		19:13:32			
Alt	▼	110	▲		

DAG 01 Unattainable RTA

If the aircraft is set to arrive *before* the RTA, the pilot should stretch the flight path to absorb extra time and ACCEPT the RTA through datalink. If the aircraft is set to arrive *after* the RTA, the pilot should immediately reject the datalink message, contact ATC via voice communication to state that the RTA cannot be met and ask for a new RTA.

RTA COMPLIANCE - II

A Required Time of Arrival (RTA) clearance, once entered and executed in the CDTI, is indicated beneath Ownship's tail tag. Ownship compliance with the RTA is indicated by a Magenta RTA/ETA tag; the ETA can be up to 15 seconds earlier or later than the stated RTA. A red RTA/ETA tag indicates Ownship is not in compliance with the RTA, which means the ETA is beyond 15 seconds early or late. When Ownship has deviated from the broadcast intent, 3 stars will appear next to the ETA. The pilot should then reenter the RTA.



This RTA depiction indicates Ownship is going to arrive at BAMBE on time.



This RTA depiction indicates Ownship is going to arrive 23 seconds earlier than the stated RTA.



This RTA depiction indicates Ownship is off the broadcast intent flight path.

TOP OF DESCENT

For information purposes only, Top of Descent (ToD) is indicated along ownship route on the CDTI, and appears in the waypoint table. DAG pilots ***should not modify*** ToD on the CDTI or in the attendant waypoint table.

WEATHER

Weather information is available on the CDTI by pressing the Wx button on the display panel, although weather is not used for the current simulations.